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Shallow Water Acoustic Reference Minehunter (SWARM)

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EXECUTIVE SUMMARY

Our goal was to demonstrate the minehunting capabilities of a system of small autonomous vehicles. We specifically chose to examine vehicles that were compatible with launch via a standard "A" sized sonobouy tube. We demonstrated that a system composed of such air-dropped vehicles can contribute significantly to the problem of clearing mines from an operational area. The cost and performance of such a system can be used as a reference by which managers can evaluate the tradeoffs with other more complex and costly alternatives.

The objective was to design a small minehunting vehicle in sufficient detail that a thorough feasibility analysis could be conducted. A concept of operations (including deployment) was also developed to determine the necessary interactions between the individual vehicles. The final result is a design that can be used for cost/performance analyses, and which provides a basis for identifying any "show stoppers" or technical issues that would critically limit the size and performance of such vehicles.

APPROACH

The approach is to use APL/UW's existing small vehicle design tools to produce an initial mechanical design. The primary issues to be resolved are endurance and search speed. Rough cost estimates will be based on COTS hardware. Actual production costs for such a vehicle will be based on APL's experience with the EMATT and Mk 38 vehicles. A strawman acoustic system is also specified so that the acoustic performance can be estimated. A standard set of tools including the Generic Sonar Model (GSM) and APL/UW's Sonar Simulation Toolset (SST) are used to conduct the performance analysis. The GSM-based simulation, called "GSM-Preview," gives a single page "snapshot" of the range/depth coverage of the sonar for a single (range independent) environment. This is done at the sonar equation level and can be used to show detection performance over a variety of minehunting environments. The SST simulation produces a time series signal for each acoustic channel including the proper phase relationships for offset phase center transducers. Simulated target signals can be added to the reverberation so that target detection and homing algorithms can be tested.

WORK COMPLETED

The timeline for this project was extended in order to coordinate with other efforts that seek to evaluate the multiple vehicle approach to minehunting (see the sections on TRANSITIONS and RELATED PROJECTS). We have produced an initial mechanical design for a small vehicle using a set of linked spreadsheets. The design is of sufficient detail that potential problem areas can be identified and a rough cost estimate obtained. We have developed a concept of operations that utilizes existing platforms to launch multiple vehicles. We have assumed a high degree of autonomy for the vehicles so that interaction and communication is kept to a minimum. The acoustic system has been simulated at both the sonar equation and the time series levels.

RESULTS

Eleven different spreadsheets were written for APL's Virtual Mooring glider (an AUV project sponsored by Dr. Tom Curtin of ONR). These formed the basis for the mechanical feasibility portion of this study. The spreadsheets were consolidated into the eight functional blocks shown in Figure 2.

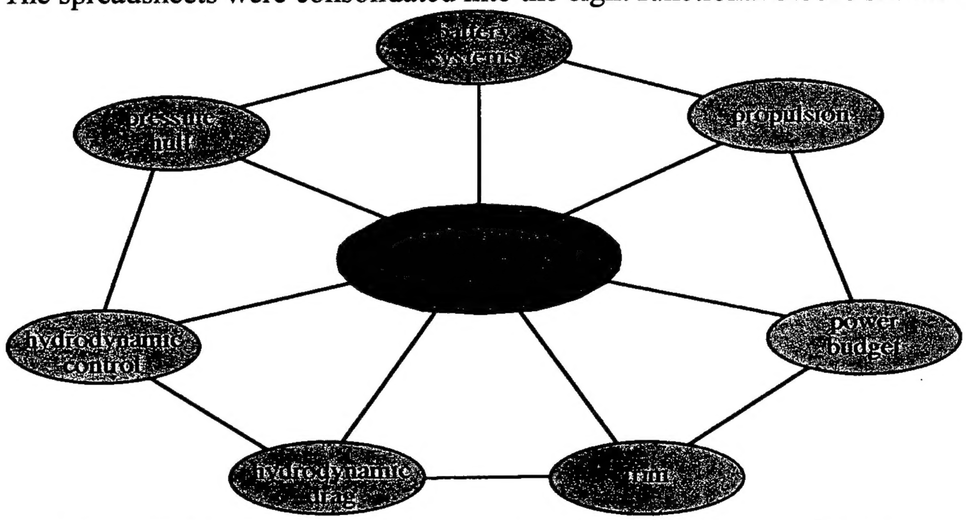

Figure 1. Mechanical design considerations (linked spreadsheets).

The central spreadsheet is a general performance summary that defines the mission speed and endurance goals. Surrounding this are spreadsheets defining the hydrodynamics (both drag and control), vehicle longitudinal and transverse trim, pressure hull, propulsion, power budget, and available battery technology. These are interrelated and solved in an iterative fashion. For instance, increasing the mission endurance would increment the required battery payload, which would increment the enclosed volume, and hence the drag. The ripple effect would continue, causing an increase in propulsion needed, and thus causing the battery payload to increase still further. The iterative or inter-related nature of this analysis is crucial to correctly exploring the "what if" options in a new design.

The SWARM vehicle that resulted from this design process has the following general characteristics:

Size: length = 91.44 cm, diameter = 12.38 cm, weight = 8.7 kg
Speed/endurance: search speed = 2.57 m/s (5 kn), endurance = 2.16 hours (20 km search range)
Maximum operating depth: 200 m
Battery pack: 5 'D' cells, $LiSO_2$ chemistry, 685 J/g energy density
Shaped neutralization charge: 2.6 kg, 60 deg cone, 1/8 in. copper liner
Search frequency: 60 kHz, pseudo-random or HOP code transmit, 6 kHz bandwidth
Search sonar: ahead-looking, 20 element, broadband array, partitioned in quadrants
Signal processing: replica correlation detection processing, homing via split beam phase
Other sensors: depth (pressure), altimeter, navigation transponder

Figure 2 shows the design layout of the vehicle. COTS components have been used wherever possible to demonstrate feasibility and keep development costs down (if a vehicle is to be built). Cost estimates will be based on these unit costs and thus will represent an upper limit on the actual production costs. The T/R array design is based on a similar 70 kHz array recently fabricated at APL/UW. No major "show-stoppers" were identified in the initial design.

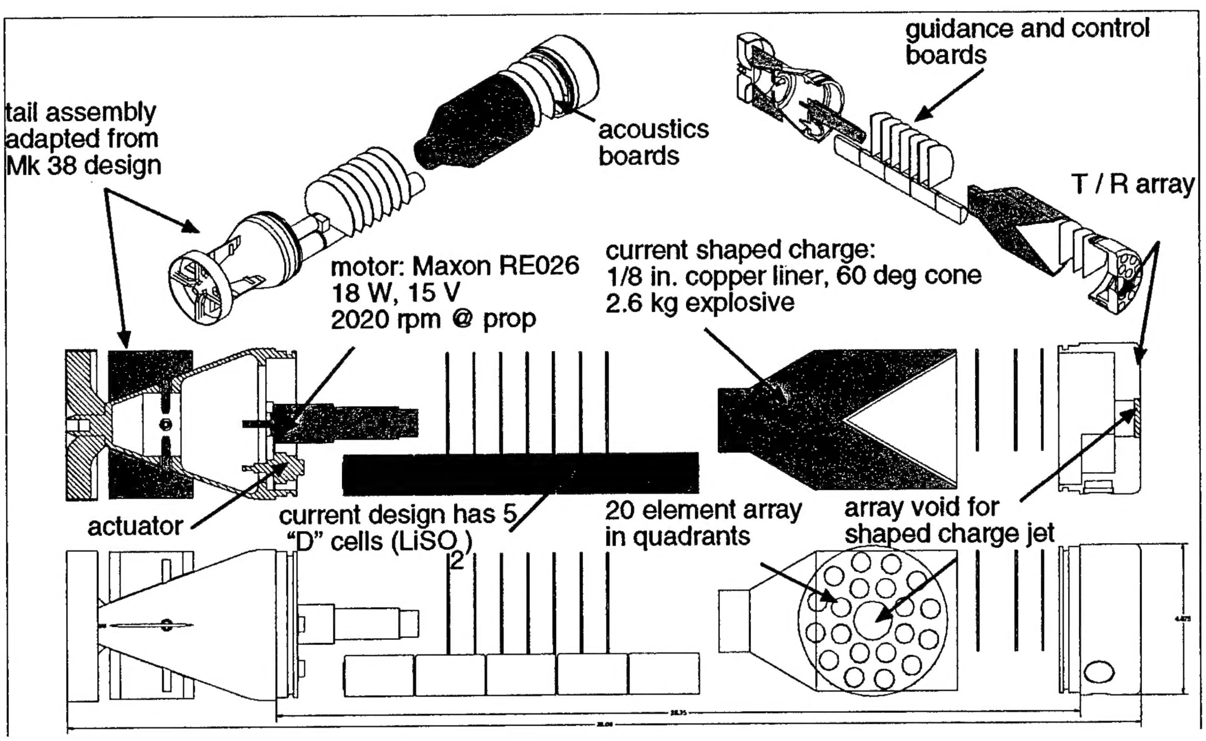

Figure 2. Initial mechanical design for SWARM vehicle (36.0 X 4.875 inches), (note: figure resolutions are greater than screen resolution, so magnification helps).

The GSM-based acoustic simulation was used to examine the range/depth and swath coverage of the vehicle in a number of minehunting scenarios. As an example, Figure 3 shows the SWARM signal excess in a relatively benign environment used for the SQQ-32 TECHEVAL (Key West, moderately downbending SSP, very fine sand bottom). The acoustic system assumptions are: 60 kHz frequency, 12 degree beampattern (4.875 in. circular piston), 190 dB//μPa source level, 6 kHz bandwidth,

arbitrary pulselength τ with a processing gain of 10*log(τ * bandwidth), and a 12 dB detection threshold. Two target strength assumptions are shown: the colored map and the numeric map to its right correspond to a -15 dB point target (moored sphere of 0.7 m diameter) centered at each point in the range/depth grid, the lower numeric map is for a –20 dB TS. The range scale maximum is 1 km, so the sonar is showing a maximum detection range of about 400 m for the –15 dB target. The depth

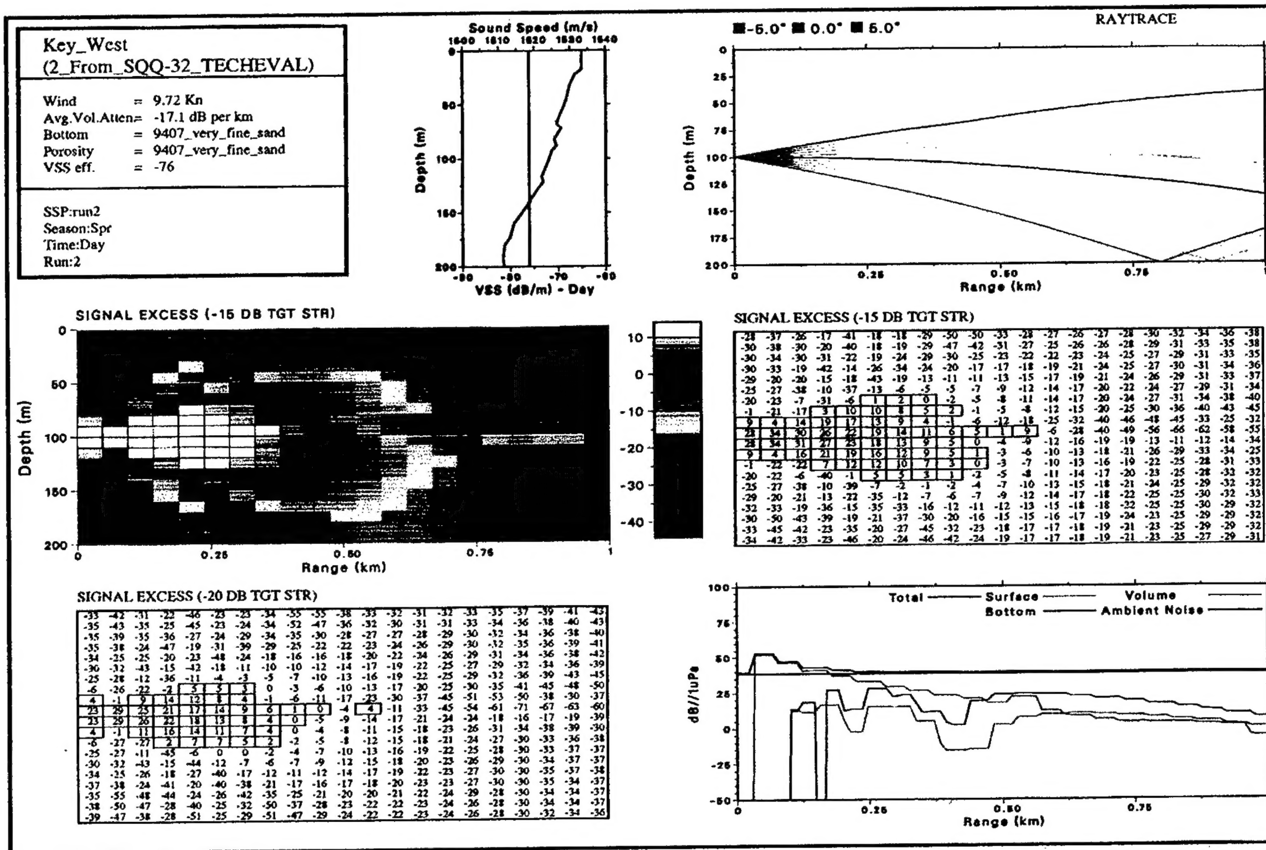

Figure 3. Example acoustic performance for SWARM in benign Key West environment.

maximum on the plot shown is 200 m, so the vertical swath maximum is about 8 cells or 80 m, occurring at a range of 250-350 m. Other environments, of course, may have more severe ray bending which can make the vertical swath an ill-defined quantity. Such cases (strongly layered SSPs for example) clearly show the advantages of multiple search depths. The horizontal swath is also about 80 m and is estimated from a similar plot with an isovelocity SSP (no horizontal ray bending).

The Sonar Simulation Toolset (SST) was developed at APL by Dr. R. Goddard to provide a time-series simulation for sonar applications[1]. We have used it to produce a set of raw sonar signals for the four quadrants of our chosen (offset phase center) receiver. The raw data can include realistic reverberation and ambient noise levels as well as the properly shifted returns from targets (point targets were used in this simple case, but multi-highlight targets are also possible). The initial SST inputs included the following simplified environment: 100 m water depth, isovelocity SSP, 10 knot wind, medium sand bottom (models from APL-UW TR 9407[2]), absorption = 16 dB/km, direct path propagation only, no noise added. The target was a single, -15 dB point highlight at a range of 300 m and a depth of 50 m. The target was slightly off the centerline (~2 degrees). The vehicle was at a depth of 50 m and had a 5 knot closing velocity. The transmit pulse was a 10 ms, 5 segment HOP code with a

6 kHz bandwidth at 60 kHz. A single 12 degree, conical transmit beam with a source level of 190 dB//μPa was used along with four similar offset phase center receive beams (up, down, left, right).

We then processed the data with a simple replica correlation detector (12 dB detection threshold), followed by an angle estimation on the largest detection using the left/right phase information (up/down steering was not implemented in the initial version). The target angle estimate is then used as input to a simple model of the vehicle dynamic motion. Given the search speed, sonar location, and commanded turn angles, a new vehicle position is calculated for the start of the next ping. New SST time series are generated for each sonar ping so that the simulated vehicle actually 'homes' on the target. Initial runs have verified detection of the −15 dB target at 300 m range and have shown that the split-beam phase data provides adequate homing capability at intermediate ranges (whether this is true for terminal homing and weapon placement has yet to be verified).

This contract was to show feasibility rather than attempt to solve all of the technical problems in detail. Reasonable mechanical design and acoustic performance for the vehicle have been demonstrated under this contract. Remaining tasks that have not completely addressed include detailed cost and overall performance estimates. Remaining technical issues include classification (magnetic and acoustic clues), warhead (volume and weight requirements), and homing (warhead placement).

IMPACT/APPLICATIONS

Part of this feasibility study was to demonstrate applications, i.e., a reasonable concept of operations in a tactical scenario of interest. We have assumed that limiting the vehicles to "A" size will pay tremendous benefits in the transportation and delivery systems. We envision a vehicle cheap enough that it can be used as a "smart bomb" against moored mines and some bottom mines. A system of such vehicles would be used as an adjunct to traditional minehunting operations. The SWARM system would pre-clear most of the moored mines and some of the bottom mines as a way of "softening up" the area. Even if a mine is easy to detect, it is still time consuming to locate, classify, identify, and neutralize. Reducing the workload will bring a dramatic reduction in total mission time. SWARM also provides an obvious mine reconnaissance capability.

Air-dropped assets have the advantage of easy and rapid deployment to any operational area. The operational envelope for such a system could include adverse conditions such as night operations and relatively high sea states. An entire system to clear a lane of mines might consist of a number of navigation pingers to be air dropped to mark the lane, several passive sonobuoys to listen for explosions, and as many SWARM vehicles as are required to cover the necessary volume. More vehicles could be dropped in successive passes if current aircraft capacity (~60 sonobuoy tubes) is exceeded. The vehicles would organize themselves into a search pattern and proceed down the lane. Information gained would include the number and timing of detected secondary explosions (mines cleared) as well as the number and timing of shaped charge explosions without secondary explosions (mines or minelike objects attacked). The time scale for SWARM operations will be on the order of hours to pre-clear a typical LST lane (500 m wide by 10 km long). A rough cost estimate for such an operation might be 50 vehicles @ $5k each ($250k).

TRANSITIONS / RELATED PROJECTS

We have shared our design concept and the mechanical design spreadsheet with the "MCM Future Studies Group" – a consortium of researchers from ARL/UT, APL/JHU, and CSS that was

seeking to evaluate small-vehicle approaches to traditional minehunting problems (ONR 321TS sponsor – Dr. Randy Jacobson). The mechanical design spreadsheets were originally written for APL's virtual mooring glider, an AUV project sponsored by Dr. Tom Curtin of ONR.

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1. "The Sonar Simulation Toolset," R.P. Goddard, Proc. Oceans '89, The Global Ocean (volume 4), IEEE publication number 98CH2780-5, 1989.

2. "APL-UW High Frequency Ocean Environmental Acoustic Models Handbook," APL-UW TR 9407, October 1994.